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A Circular Ontology of Matter, Information, Consciousness, and History

Prologue

1 In an ancient image, a serpent devours its own tail: the **Ouroboros**, a timeless symbol of a self-contained loop. At the dawn of our universe, there was only matter and energy—vast fields of hydrogen gas, silent stars in formation. Eons passed, and from this **matter** arose complexity; atoms bonded into molecules, molecules into living cells carrying **information** in the form of genetic code. Through evolution, some of these living structures attained **consciousness**, a spark of awareness kindled in neural networks of brains. Conscious minds, in turn, began weaving narratives, storing memories, building societies—giving rise to **history**, the cumulative record of collective experience. This progression from matter to information to consciousness to history did not merely follow a straight line; instead, each stage began to influence and reshape the previous ones in a profound circular dance. Conscious beings use knowledge to alter the material world; historical developments encode new information; information feeds into evolving consciousness. Thus, the **universe bends back upon itself**, as observers and participants become agents in the very cosmos that produced them. The cosmos, like the Ouroboros, **curves into a circle**: matter begets mind, mind makes history, and history transforms matter again.

In this paper, we present a full narrative and theoretical exploration of a circular ontology of matter, information, consciousness, and history. We weave rigorous philosophical argument with scientific insight and poetic reflection, tracing a loop in which these four fundamental domains are inseparably linked. The structure of our inquiry is itself circular, beginning and ending with reflective narrative. **Part I** lays the philosophical groundwork, questioning traditional linear ontologies and introducing the need for a self-referential framework. **Part II** examines how humans create meaning through **metaphor-data-form loops**, showing that even our pursuit of knowledge is circular. **Part III** develops the idea of a **self-referential ontology**, wherein any account of reality must include itself as a part of reality. **Part IV** explores **recursive models** in science and consciousness, illustrating how feedback loops underlie mind and nature. **Part V** synthesizes the previous parts into a cohesive model – a circular ontology connecting matter, information, consciousness, and history – and visualizes this with conceptual diagrams. **Part VI** discusses the implications of this ontology and outlines **experimental designs** and formal approaches (with details in Appendix E) to test and elaborate the model. Finally, the **Epilogue** returns to a reflective mode, contemplating the broader meaning of this ontological circle for our understanding of the universe and ourselves.

Throughout, we maintain a tone balancing analytical rigor with creative insight. The journey ahead is both philosophical and scientific, traversing ideas from ancient wisdom to modern information theory, from quantum physics to cognitive science, and from human history to abstract mathematics. In embracing this circular ontology, we aim to arrive, in T.S. Eliot's words, "where we started and know the place for the first time" – to see matter, information, mind, and history not as isolated categories, but as interwoven aspects of one self-creating reality.

Part I: Philosophical Foundations of a Circular Ontology

Ontology is the branch of philosophy concerned with what exists and how the fundamental categories of being relate. Classical ontologies often assume a **hierarchical or linear order** of reality: for example, **materialism** posits matter as the base from which life and mind emerge, whereas **idealism** posits mind or spirit as primary, giving rise to the material world. In contrast, a **circular ontology** proposes that the basic elements of existence—here, **matter, information, consciousness, and history**—form a closed loop of mutual causation and co-creation. No single element is the absolute foundation; instead, each influences and is influenced by the others in an ongoing cycle. This idea challenges deeply ingrained linear paradigms and invites us to think in terms of **feedback loops** and **self-reference** rather than one-way chains of cause and effect.

One motivation for a circular ontology comes from longstanding philosophical puzzles. Consider the classic mind–matter problem: if matter produces mind (as materialists claim), how can mind in turn affect matter (as our everyday experience of agency suggests)? The traditional one-directional view struggles to explain phenomena like conscious intention influencing physical actions, or subjective experience arising from inert matter. A circular perspective, by contrast, allows for **bidirectional influence**: matter gives rise to mind, but mind also acts back on matter (for example, via deliberate action in the world). In a circular ontology, **cause and effect become entwined**; as philosopher Gregory Bateson once noted, "the pattern that connects" living and nonliving systems is one of circular causality and feedback, not linear mechanisms. The whole (such as a conscious organism plus its environment) may be **more than the sum of its parts** and cannot be understood by reduction to a single starting point.

This perspective finds resonance in multiple philosophical traditions. **Georg W. F. Hegel**, for instance, viewed history itself as a **process of Spirit (Geist) coming to know itself**, suggesting a deep self-referential dynamic: the world's evolving consciousness (through humanity) is both product and agent of historical change. In Hegel's philosophy, world history has a teleological character—the "aim of world history is the development of the self-consciousness of spirit"—and this aim is only realized through the historical process itself. In other words, **history is the means by which Mind (or Spirit) discovers its own nature**, implying that the observer (Spirit) and the observed (historical world) are intertwined in a single trajectory. Such ideas foreshadow a circular ontology: the ultimate knower and the known emerge together through a dialectical loop.

Non-Western philosophies, too, have embraced circular or cyclical views of reality. In Buddhism, the doctrine of **pratītyasamutpāda** (dependent co-arising) holds that phenomena exist only in interdependence; nothing stands alone as first cause. While traditional Buddhist thought might not explicitly enumerate matter, information, consciousness, and history in our terms, it emphasizes a web of relations and feedbacks wherein cause and effect loop back into each other. Similarly, the ancient symbol of the **Ouroboros** encapsulates a mystical intuition of self-reference: existence renewing itself, **the beginning also the end** [1]. These perspectives reinforce the notion that linear causality may be an incomplete lens, and that a more holistic, circular understanding is needed to capture the richness of reality.

Modern science and philosophy of science also push us toward this conclusion. The role of the **observer** in contemporary physics provides a vivid example. In quantum mechanics, certain phenomena have no definite reality until observed; the classic thought experiment of Schrödinger's cat or the empirical facts of wavefunction collapse suggest that **the act of observation is not a passive revelation of reality but an active participation in it**. **John Archibald Wheeler**, a pioneering physicist, went so far as to propose a "participatory universe": in his view, every physical "it" (object or event) derives its existence and meaning from "bits" of information created by yes-or-no questions posed by observers. Wheeler coined

the phrase **"it from bit"** to capture the idea that information is fundamental to the physical world. He even envisioned the universe as a **self-excited circuit**, famously drawing a U-shaped diagram of the cosmos observing itself: as the universe evolves, it gives rise to observers (us), who in turn define the reality of the universe, even its earliest stages. In Wheeler's words, "every physical quantity, every it, derives its ultimate significance from bits" – all things physical are **information-theoretic in origin** in a **participatory universe**. This radical view implies a circular causation between physics and observation: the material world generates observers who generate informational questions that "create" the material reality. The **observer and the universe form a closed loop**.

These considerations highlight a need for ontology to be **self-referential** and **non-linear**. A circular ontology posits that matter, information, consciousness, and history each exist because of the others, not in spite of them. None of these can be fully explained in isolation:

- **Matter** (in the sense of physical substance and energy) underpins the existence of information structures, conscious beings, and the unfolding of history; yet matter's very laws and constants may be intimately tied to informational and observational processes.
- **Information** (patterns, data, signals) is physically instantiated in matter (e.g. DNA, neural connections, computer memory) but also requires conscious interpretation to become knowledge; information accumulates over history and in turn shapes both history and how matter is organized (think of engineered materials or genetic modifications driven by knowledge).
- **Consciousness** arises from complex material and informational processes (e.g. brains integrating information), but once present, consciousness interprets information and can direct material affairs, playing a key role in historical events. Conscious experience also defines what information means, linking the subjective aspect of reality back to the objective.
- **History**—the temporal trajectory of systems, especially human societies—is shaped by conscious choices and interpretations. History is not just a record of material events but of **meaningful actions** undertaken by conscious agents based on information. In turn, the outcomes of history (from cultural norms to technological infrastructures) condition the material environment and the information landscape for future generations of conscious beings.

In a circular ontology, these four elements form a **metaphysical loop**. Rather than thinking of a base layer (matter) from which higher layers (life, mind, culture) emerge unidirectionally, we propose to think of a **closed circuit** or **cycle**. Matter yields information, which yields consciousness, which yields historical trajectories, which then transform the material conditions, and the cycle continues. This idea requires us to accept a form of **reciprocal causation** and **emergent order**: the higher-order phenomena (consciousness, culture) are born from lower-order ones (physical matter and information), and simultaneously those higher-order phenomena feed back to reconfigure the lower-order ones.

Such a viewpoint aligns with the concept of **emergence** in systems theory: new properties (like life or mind) emerge from complex interactions of simpler parts, and once emerged, those properties exert **downward causation** (influencing the behavior of the parts). Consciousness, for example, emerges from neurons firing, but a conscious thought (a high-level phenomenon) can cause certain neurons to fire or muscles to move (altering the low-level physical domain). The loop is closed when we recognize that those muscle movements can alter the external world, feed new sensory information back in, and so on.

In summary, the philosophical foundation for a circular ontology rests on recognizing **the insufficiency of linear causation** for explaining reality. The world is not a simple top-down hierarchy (as strict idealism might hold) nor a bottom-up machine (as strict materialism might hold); it is better described as a **self-organizing, self-referential network** of relationships. We proceed next to examine how even our methods of inquiry—our generation of knowledge and meaning—exemplify circular dynamics, through what we call **metaphor-data-form loops**.

Part II: Metaphor–Data–Form Loops – How We Create and Perceive Reality

Our understanding of the world is constructed through a continuous loop between what we observe, the concepts we use to interpret those observations, and the imaginative frameworks that guide our search for new observations. We call this the **metaphor–data–form loop**, a cycle by which **metaphors** (conceptual models and analogies), **data** (empirical observations), and **forms** (formal structures or theories) co-evolve. This epistemological loop is a microcosm of the circular ontology: it shows how human consciousness (with its creativity and metaphors) interacts with information (data) and imposes form (theories, models) in a recursive manner. It demonstrates that even the act of knowing is not linear (we do not simply gather data and then form theories in one direction) but iterative and circular.

Metaphor here stands for the imaginative leap or analogy that helps us make sense of data. Cognitive linguists George Lakoff and Mark Johnson famously argued that our ordinary conceptual system is fundamentally metaphorical. We understand new or abstract domains by implicitly comparing them to familiar ones—**metaphors structure our thought**. For example, we speak of time as a "river" or the mind as a "computer," using one domain to conceptualize another. These metaphors are not just poetic flourishes; they shape the questions we ask and the interpretations we give to raw experience. In science, metaphors often underlie theoretical models: Niels Bohr's model of the atom likened electrons orbiting a nucleus to planets orbiting the sun, providing a visual metaphor that guided early atomic physics. In neuroscience, it has been common to use the metaphor of the brain as a kind of computer or the mind as software, which channels how experiments are designed and how data are interpreted.

Data, in turn, are the observations and measurements we collect from the world. Data do not come pristinely and independently; they are always gathered through some conceptual lens or experimental setup which is influenced by prior metaphors and theories. As Thomas Kuhn noted, **there are no theory-independent observations**—what scientists notice and record is shaped by what their current paradigm deems relevant. In practice, this means we **cannot separate the empirical from the conceptual**: our metaphors and theories determine what counts as data, and surprising data can in turn prompt new metaphors or force revisions of form.

Form refers to the formal structures, theories, or models that we construct to organize and explain data. These include mathematical equations, logical frameworks, taxonomies, and so forth. Form is where metaphor and data are codified into an explicit system. For instance, Newton's laws provided a formal framework (laws of motion and gravity) that both arose from empirical observations (Kepler's laws, Galileo's experiments) and were guided by metaphors (the clockwork universe metaphor, seeing the world as a mechanical system). Form gives structure to understanding and allows predictions, but it is not static. When new data conflict with the existing form, scientists must adjust the form—often by introducing a new guiding metaphor or conceptual scheme.

These three—metaphor, data, form—interact in a **continuous loop** rather than a straight line. We can outline the **metaphor–data–form loop** as follows:

Figure 1: A schematic of the metaphor–data–form loop in knowledge formation. Metaphors (conceptual analogies and imaginative models) guide what data we collect and how we interpret it. The data, once gathered, inform the development or adjustment of formal theories (forms). Those formal structures in turn inspire new metaphors or refine old ones, guiding the next cycle of observation.

In practice, **scientific inquiry** exemplifies this looping process. A researcher begins with an intuition or metaphor (for example, James Clerk Maxwell's **metaphor of an intelligent "demon" sorting molecules**

to probe the relationship between information and entropy). This metaphor leads to a thought experiment and suggests data to look for or measure (the speeds of gas molecules in Maxwell's case). The data are analyzed and perhaps a formalism is developed (Ludwig Boltzmann and others translated these ideas into the formalism of statistical mechanics). The formalism might then reveal a paradox or gap, prompting a new metaphor or model. In Maxwell's demon scenario, the paradox of seemingly violating the second law of thermodynamics was eventually resolved by Rolf Landauer's insight that **erasing information incurs a thermodynamic cost**, which is a formal principle tying information to entropy. Landauer's principle ($E \ge k_B T \ln 2$ of energy dissipation per bit erased) was itself guided by a conceptual shift: viewing information as physical. That shift—"information is physical"—is a metaphor as much as it is a statement of fact, and it has since guided countless experiments and technologies.

The interplay is not only evident in revolutionary paradigm shifts but in everyday reasoning. Even in mundane perception: our **brains use predictive metaphors to make sense of sensory data**. The cognitive scientist Andy Clark describes the brain as a prediction machine that continuously generates hypotheses (like metaphors or models) about incoming sensory data and updates them based on prediction errors (discrepant data) — another feedback loop of mind and world. Thus, perception itself can be seen as a loop of expectation (form), observation (data), and adjustment (new form), anchored by metaphors (we often unconsciously assume, for instance, that light comes from above, a heuristic metaphor that guides visual perception).

Historically, the **development of science and culture** also follows the metaphor–data–form loop. Thomas Kuhn, in The Structure of Scientific Revolutions (1962), detailed how scientific fields undergo periodic "paradigm shifts," which we can interpret as major loop resets. A paradigm (form) guided by core metaphors (say, the Newtonian view of absolute space and time) accumulates anomalies in data (e.g. Michelson–Morley's null result for the ether wind). Eventually a new metaphor is proposed (Einstein's insight of relativity, perhaps informed by metaphors of geometry and invariance) leading to a new formal theory (the theory of relativity) that reinterprets old data and directs new experiments. Kuhn later explicitly acknowledged the role of metaphor in science, stating that **"metaphors play an essential role in establishing links between scientific language and the world"** and that changes in fundamental metaphors accompany scientific revolutions. In short, **the language and concepts of science evolve through metaphorical leaps**, guided by data and formalization, in a repeating cycle.

Crucially, the metaphor–data–form loop is **self-correcting yet creative**. Because it is a loop, it has no absolute beginning—one can enter at any point. Sometimes a wild metaphor or analogy (like Kekulé's dream of Ouroboros leading to the structure of benzene) drives the discovery of a form; other times a serendipitous piece of data (X-rays revealing DNA's double helix) prompts a new conceptual metaphor ("the twisted ladder" of DNA) and then a formal model of genetics. The loop underscores that **our knowledge is not built in a straight line from observation to theory**, but in a **recursive process** where **interpretation (mind) and observation (world) are entangled**.

This has deep ontological implications: it suggests that **the knowing mind and the known world form a coupled system**. The metaphors and theories in our consciousness actively shape what the world "reveals" to us as data, while the world's feedback reshapes our consciousness. Here we see, on the epistemic level, a parallel to the circular ontology: **consciousness (with its creative metaphors) and information (data) are locked in a dance**, and over time this dance becomes part of the story of our species (history of science, cultural evolution) which then alters our material practices and environment (think of how the scientific revolution changed technology and industry, literally transforming matter in our world).

To illustrate with a concrete historical loop: in the early 20th century, the **metaphor of the gene as information carrier** took hold (formulated by early geneticists). This guided experiments (data) in

heredity and molecular biology. The data (like patterns of inheritance, later the structure of DNA) led to formal models (Mendelian inheritance laws, Watson-Crick model of DNA as a double helix). That formal understanding in turn reinforced the metaphor of "organisms as information-processing systems" and spawned new metaphors (the genome as a "blueprint" or "code"). Those metaphors now guide the burgeoning field of bioinformatics and genetic engineering, where we literally manipulate matter (DNA molecules) based on an informational metaphor. And indeed, this feedback has shaped history (the biotechnology revolution, medical advances, etc.).

Thus, the metaphor–data–form loop is not only a cycle of knowledge but a bridge between **mind and matter via information**. It shows in microcosm how **consciousness (with intentionality and imagination) engages with information (meaningful data) to affect the material world** (through technology, experiments, and actions), which then produces new information and so on. In the next part, we build on this epistemic loop to delve into the concept of **self-referential ontology**—the idea that any comprehensive account of reality must account for itself being formulated from within reality. We will see that the loops we engage in while knowing the world hint at a deeper truth: **reality might be structured such that it can refer back to itself**, with human consciousness and history being central to that self-reference.

Part III: Self-Referential Ontology – The Universe Describing Itself

One of the most profound implications of a circular ontology is that it is **self-referential**. A **self-referential ontology** means that the ontology (the description of what exists) includes, in the very fabric of existence, the capability to **refer to or represent itself**. In simpler terms, the universe contains within it elements (like conscious minds, or records, or models) that re-present the universe itself. This idea forces a departure from the traditional view of an external, observer-independent reality that can be described from the outside. Instead, it embraces the notion that **the universe is, in a sense, observing and describing itself through us**.

Human consciousness is the clearest example of this self-reference. We are made of physical matter, produced by the cosmos, and yet we are able to form an ontology—a conceptual model—of the cosmos itself. The **map is part of the territory**: any scientific theory or philosophical ontology we devise is itself a product of the very world it attempts to describe. This circularity is not a paradox to be avoided but a fundamental feature of reality. As physicist John Wheeler emphasized, we live in a participatory universe where the **observer is part of the observation**. The act of knowing the world injects something back into the world. The quest for a "Theory of Everything" in physics, for instance, must grapple with the fact that **theory-builders (physicists) are themselves physical entities within the universe**. This means that any truly complete theory might have to account for the emergence of those theory-builders and the knowledge they generate—a deeply self-referential requirement.

Self-reference is a well-known concept in logic and mathematics (e.g., Gödel's incompleteness theorems rely on self-referential statements within formal systems). Gödel showed that any sufficiently powerful formal system can produce statements that assert their own unprovability, implying a kind of loop: the system can talk about itself. In a similar way, the **universe can "talk about itself"** through structures within it. **Douglas Hofstadter**, in Gödel, Escher, Bach and I Am a Strange Loop, argues that consciousness is essentially a **"strange loop"**: a self-referential pattern arising in a complex system that can perceive and represent itself. He uses the metaphor of the brain as an example of a high-level symbolic system that, like Gödel's sentences, **turns back on itself**. The "self" (the "I") is, in Hofstadter's view, a narrative and symbolic construct that the brain creates about itself – essentially, **the brain's model of the brain**. When the brain's symbolic activity becomes sufficiently complex and reflective, it invents the concept of self and in doing so becomes self-aware. This is a prime example of ontology that is self-referential: the

"I" exists as a phenomenon that is about itself. Or as Hofstadter succinctly puts it, **the self is a self-referential strange loop**.

Nature offers examples of self-referential structures at other levels as well. Consider the fundamental biological loop of **DNA and proteins**. DNA contains information (genes) that code for proteins, and among those proteins are the very enzymes that replicate and repair DNA. Thus, the information (DNA sequence) is interpreted and maintained by machinery (proteins) that is encoded in that information. This is a self-referential molecular system: the genome encodes the means to preserve and propagate itself. In a broader sense, life is **autopoietic** (self-making), as theorists Humberto Maturana and Francisco Varela described – living cells continuously produce the components that in turn produce those same cells. The **circular logic of life** (e.g., the cell's components collectively produce the cell) is a form of self-referential existence. It defies a simple linear cause (no single molecule is "first cause"; the network as a whole is self-sustaining). This biological example foreshadows how **conscious organisms produce culture and knowledge that eventually reflect back on those organisms**. For instance, the human brain (product of DNA and biology) creates science and technology (cultural information) that allows us to manipulate genes and ecosystems. Humanity is now literally re-engineering the DNA from which it arose, through biotechnology – a striking real-world instance of the universe (through human minds) acting back upon the codes of life that made those minds.

Another illustrative domain is **cosmology and the anthropic principle**. The anthropic principle in its strong form suggests that the universe's laws are such as to allow the emergence of observers, and indeed, only a universe that permits observers can be observed. Some interpretations of quantum mechanics, like Wheeler's own views or John von Neumann's, have posited that the presence of consciousness might be necessary to "collapse" the quantum wavefunction, thereby giving reality a definite state. If, in some still mysterious way, the existence of observers is necessary for the existence of a concrete universe, then we truly have a **cosmic self-reference**: the universe gives rise to conscious observers who in turn give reality to the universe (at least in the sense of making its possibilities actual). Wheeler's "self-excited circuit" diagram captured this by drawing the universe as a big loop with an eye (observer) at one end observing the universe at the other end, but in fact it's one continuous line – **the universe observing itself**.

Self-referential ontology also manifests in **history and culture**. Humanity's collective understanding of the world—our sciences, religions, philosophies—are themselves part of the world. Ideas in human societies can loop back and change the course of those societies (for example, **Karl Marx's philosophical ideas about history became themselves historical forces**, as Marxism, once disseminated, affected the material and political conditions of nations). This is an example of **a concept altering the very reality it purports to describe**. Likewise, environmental awareness: once humans conceptualized the biosphere and realized our role in climate change, that knowledge started feeding back into history in the form of policy changes, technological innovation, etc., altering the physical world (hopefully mitigating harm). Our capacity for reflection means history is often **history reflecting on itself**. Historians and social scientists analyze past patterns, and these analyses (if absorbed by societies) can influence future behavior, potentially avoiding repeating mistakes or deliberately emulating past successes. In this way, **history gains self-awareness** through us, making our species a potential agent of directed change rather than blind progression.

In a self-referential ontology, **the distinction between map and territory blurs**. Any map (representation) we draw is part of the territory (the universe) and can, in advanced systems, influence the territory. This compels us to adopt what cyberneticist Heinz von Foerster called a "second-order" perspective: include the observer in the observation, include the creator of a model in the model. Philosophically, this resonates with reflexive philosophies (like some strands of phenomenology, where the philosopher recognizes that their own consciousness is both subject and object of study). The

ontology we propose does exactly this: it includes **consciousness and history as fundamental categories alongside matter and information**, thereby explicitly acknowledging that **the describer (mind) and the described (world) co-arise**.

One might worry that self-reference leads to vicious circularity or paradox. However, just as Gödelian loops in mathematics reveal new truths (rather than simple contradictions) and just as feedback loops in engineering stabilize systems (rather than crash them, if properly managed), the **self-referential loops in reality can generate stable structures and dynamic balance**. The human mind does not implode because it thinks about itself; rather, that ability is key to our intelligence. Similarly, a society that examines its own behavior (history) can achieve reforms and improvement. The universe, by having parts of itself that model itself (like scientists building cosmological models, or a starfish's DNA encoding how to grow a new limb), demonstrates a form of **consistency through reflexivity**. It is as if reality has a built-in capacity for **self-knowledge**.

In **Appendix E**, we will formalize some aspects of self-reference using the language of category theory and information theory. For now, we acknowledge conceptually that any adequate ontology must "contain itself" – it must account for the fact that the theory is being formulated from within the world by conscious agents with limited information. **The circular ontology meets this criterion** by making consciousness and its products (information, historical context) integral parts of what exists, rather than awkward add-ons or illusions.

Having established that reality, as we see it, involves self-reference and circular causation, we turn next to how we can model these ideas more concretely. **Part IV** will delve into recursive models and patterns that appear across different domains, showing how recursion and feedback provide a unifying principle – a principle that will be crucial for any formal model of the circular ontology.

Part IV: Recursive Models in Nature and Mind

Recursion and self-similarity are ubiquitous patterns in the natural world and in abstract systems. A **recursive model** is one in which a structure repeats or refers to itself on multiple levels. In the context of our circular ontology, recursive models provide a way to understand the complex feedback loops that connect matter, information, consciousness, and history. They reveal how the same underlying principles can manifest across different scales and domains. In this part, we explore examples of recursion in physical systems, biological and cognitive systems, and even social systems, laying the groundwork for formalizing the circular ontology.

One of the simplest recursive patterns in nature is the **fractal**. Fractals are structures that exhibit self-similarity across scales: zooming in on a part of a fractal yields a shape that resembles the whole. The recursive generation of fractals (e.g., each branch of a fern looks like a smaller fern) is a visual metaphor for how simple iterative rules can produce complex, holistic structures. While fractals themselves are usually static geometrical objects, their generation is recursive and iterative. This is analogous to how complex systems (like life or mind) can arise from repeated applications of simple interactions. For instance, the branching of blood vessels or neurons has a fractal character, optimizing distribution networks by repeating a branching pattern. This hints that **recursion underlies efficient, emergent design** in biology: instead of a top-down blueprint, a simple rule (branch when volume exceeds X) applied repeatedly yields an organism's vascular system.

In cognition, recursion shows up vividly in **language and thought**. Human language is recursive: sentences can contain other sentences (through clauses), theoretically without limit. This ability is thought to be a hallmark of human cognitive power. It allows us to embed ideas within ideas ("John

believes that Mary knows that...") – a form of **mental self-reference and nesting**. Similarly, thoughts can turn inward (we can think about thinking, know about knowing). The **global workspace theory** in cognitive science posits a kind of recursive broadcast: information from various unconscious processes gets iteratively broadcast to a global workspace (conscious awareness), which in turn influences those processes – a feedback loop that aligns with conscious reflection. **Integrated Information Theory (IIT)** of consciousness, which we touched on earlier, explicitly states that consciousness arises from **"feedback loops" of cause and effect within a system that make a difference to themselves**. According to IIT, a conscious system is one where the information is integrated in such a way that the whole system has causal properties that its parts do not, and crucially, that there are **reentrant connections** (reciprocal interactions) among the elements. In other words, only a system with **recursive connectivity** (like the thalamo-cortical loops in the human brain) can generate the unified, self-referential experience we call consciousness. Neuroscientific evidence supports this: the cortex is full of bidirectional connections, and conscious perception seems to require these recurrent loops (for example, when feedforward sensory input is not followed by feedback from higher cortical areas, the stimulus may not be consciously perceived). The **reentry** concept introduced by neuroscientists Gerald Edelman and Giulio Tononi emphasizes that signals must circulate in loops for consciousness to emerge, aligning with the idea that **recursion = reflection** in the brain.

Another dimension of recursion in mind is the **self-modeling of the self**. We discussed Hofstadter's view of the "I" as a strange loop. Psychologically, this appears as the brain constructing a **model of the world that includes a model of itself within that world**. We maintain a mental representation of "who I am" (personality traits, memories, body schema, etc.), and we can imagine ourselves in hypothetical scenarios (projecting the self-model into future or past). This ability essentially means that the mind can run a simulation that includes itself as a character – an inherently recursive operation. Such self-modeling is likely crucial for social cognition (predicting others' actions by simulating oneself in their shoes, a kind of meta-recursion known as **theory of mind**). In artificial intelligence, researchers have similarly found that allowing an AI system to model its own knowledge (to have a meta-representation of what it knows or doesn't know) can improve learning – an artificial analog of a system becoming aware of itself.

In **evolutionary dynamics**, we also see recursive patterns. Genetic information (DNA) leads to organisms, which through behavior can influence which genetic information gets passed on (natural selection forms a feedback loop between genes and environment). On top of that, humans have introduced an extra recursive layer: **culture and technology evolve**, and those cultural traits (like scientific knowledge or tools) affect which genes are successful (for example, the spread of dairy farming led to increased prevalence of lactose tolerance genes in some populations – a gene-culture coevolution loop). Now, with biotechnology, we have an unprecedented recursion: culture (via scientific knowledge) allows us to directly modify genes, feeding back into biological evolution. This is evolution becoming **self-guided** to an extent – a species taking control of its own genetic destiny, a loop of evolution acting on itself.

Even **social systems and history** exhibit recursive modeling. Political and economic systems adjust based on theories about themselves: consider how Keynesian economics (a theory) influenced governments to intervene in markets, thereby changing the economy to better fit (or sometimes misfit) the theory; then new economic theories emerged in response to those changes (e.g., monetarism in response to outcomes of Keynesian policies). In international relations, nations often act based on what they think other nations think, leading to feedback loops of perceptions (e.g., the recursive "do they believe we will attack? If they believe we will, they might preempt, so should we preempt first?" reasoning during conflicts). These are essentially **higher-order feedback loops** in collective cognition, sometimes modeled using game theory, which itself uses recursive logic (my strategy depends on my model of your strategy, which depends on your model of mine, etc.). History can thus be seen as shaped by reflexive cycles—**ideas about history or society alter the course of history or society**. For example,

the concept of “democracy” spread, partly because people observed the success of democracies and desired the same, creating a self-fulfilling expansion of that political form. Similarly, awareness of historical cycles of rise and fall might influence a civilization’s attempt to break the cycle, a reflexivity that could lead to novel historical trajectories.

Because recursion is so fundamental, we can attempt to capture our circular ontology in recursive formal models. One powerful formal approach is through **category theory**, which deals with objects and morphisms (arrows) in very general terms. Category theory inherently accommodates recursive structures, such as **endofunctors** (functions from a category to itself), which can have fixed points. We might conceptualize an **“ontology category”** `Ont` whose objects include states or configurations involving matter (M), information (I), consciousness (C), and history (H). The interactions between these can be seen as morphisms: for instance, a morphism `f: M -> I` could represent the process of extracting information from matter (e.g., measurement or data recording), `g: I -> C` could represent interpretation or integration of information into consciousness, `h: C -> H` could represent conscious action creating historical events, and `j: H -> M` could represent the historical influence on material conditions (e.g. technological change affecting the physical environment). The **composite** `j ∘ h ∘ g ∘ f: M -> M` would then be an endomorphism on the object M (matter), effectively describing a full cycle from matter back to matter via information, consciousness, and history. If this composite is (or approaches) the identity morphism, it would imply that the loop brings the system back to its starting point (perhaps an equilibrium). More interestingly, **iterating the loop** (going around multiple times) could represent evolutionary or developmental processes where each cycle transforms the state further. Category theory also has the concept of **initial objects** and **fixed points** (via limit/colimit or via fixpoint combinators in lambda calculus, which category theory can represent). One might say that the circular ontology looks for a **fixed point of a functor** that cycles through M, I, C, H. We will articulate such formal ideas more concretely in Appendix E, but the key intuition is that **recursion provides a language to speak about self-contained loops** rigorously.

Another formal aspect is the use of **entropy and information measures** to quantify recursion. We may attempt to quantify how much information each domain provides to the next in the loop. For example, **mutual information** $I(\text{Matter}; \text{Information})$ could measure how much the state of the material world tells us about the data we collect (clearly high if our instruments are good). Likewise, $I(\text{Information}; \text{Consciousness})$ could relate to measures of integrated information (phi) in consciousness studies, which quantifies how much a system’s internal state (information structure) is unified (this is essentially information that the whole has beyond the sum of parts). **Entropy** can also be used to track the loop: matter has entropy (thermodynamic disorder), information has entropy (uncertainty or Shannon entropy), and perhaps we can define an entropy for consciousness (uncertainty in mental state or entropy of neural activity) and for history (entropy as unpredictability or complexity of historical configurations). A recursive model might reveal an **entropy flow** in the loop. For instance, when consciousness gains information (reduces uncertainty by learning), it typically expends energy and increases entropy in the environment (as per Landauer’s principle, erasing one bit of uncertainty yields at least $k_B T \ln 2$ of entropy in the surroundings). This suggests a **balance**: the loop can be seen as processing entropy—taking low-entropy structures (ordered matter) to create knowledge (lowering information entropy in the mind) but at the cost of dumping entropy into the environment (through heat, waste, etc.). Then that environment entropy might drive further physical processes (e.g., waste heat radiates to space, affecting Earth’s history). In a sense, **each cycle of the loop might obey a conservation law**: you can’t gain information or create historical order without paying a thermodynamic price. Recursive models allow these constraints to be expressed in equations and algorithms, ensuring our ontology is consistent with known physical laws like the second law of thermodynamics.

Recursion also provides hints for experimental designs. A recursive model often suggests that **to affect one part of the system, you can intervene in another part and watch the feedback**. For example, if consciousness and information are in a loop, then **perturbing the information flow** should alter consciousness, and vice versa. This is exactly what neuroscientists do: they use methods like Transcranial Magnetic Stimulation (TMS) to perturb neural loops and then measure changes in conscious experience or EEG signals to infer the causal loop dynamics. Another example: if history and matter are in a loop, altering material conditions (say, a major climate intervention) should change the course of history, and understanding that feedback helps us plan interventions. These recursive cause-effect chains are testable via systematic perturbation and observation – essentially a control theory approach to a complex system that includes the controller.

Having surveyed the significance of recursive patterns, we now have a conceptual toolkit to integrate everything. We have seen how matter, information, consciousness, and history can be conceptualized as interconnected via feedback loops at multiple scales. In the next part, **Part V**, we will bring these strands together explicitly into a single **integrative model of the circular ontology**. We will depict and explain how the four domains close into a cohesive cycle, and consider the dynamic behavior of this cycle. We will also discuss qualitatively what stability or growth means in this context – for example, can the loop amplify knowledge and complexity indefinitely, or are there limiting factors? With the integrated model in hand, we can then move to practical considerations of how to explore and verify it, which will be the focus of Part VI and the formal appendix.

Part V: Integrating Matter, Information, Consciousness, and History – The Ontological Circle

We now arrive at the heart of the thesis: the integrated **circular model** linking matter, information, consciousness, and history into one self-reinforcing ontology. Having laid out components and smaller loops individually, we can show how they connect into a grand cycle. This part presents the circular ontology explicitly, discusses each linkage in the cycle, and examines the overall behavior of the loop. We also consider the philosophical implications of viewing reality in this unified way.

At its simplest, the circular ontology can be visualized as a **ring of four nodes** (M, I, C, H) with arrows connecting each to the next in a cycle:

Figure 2: A conceptual diagram of the circular ontology linking **Matter (M)**, **Information (I)**, **Consciousness (C)**, and **History (H)**. The arrows indicate the cyclical influences among the four domains: M → I (matter generates information), I → C (information gives rise to or informs consciousness), C → H (consciousness produces history through intentional actions and communications), and H → M (historical processes alter the material world).

This diagram is a qualitative picture of the ontology. Let us unpack each connection (arrow) in detail:

1. **Matter → Information (M → I):** This link represents the generation of information from the physical world. Matter and energy in various configurations produce signals and data. Examples include photons carrying images of objects, vibrations traveling through air as sound, or the patterns recorded by scientific instruments. Fundamentally, every measurement is an extraction of information from a material system. When a geologist studies rock strata, the **material record becomes information** about Earth's history. When data is recorded on a hard drive, the magnetic states of matter encode bits of information. Even biologically, the structure of the world influences the information content that organisms receive (light entering eyes, chemicals stimulating taste, etc.). In a Shannon information sense, any reduction of uncertainty about the state of a physical

system is information gained; thus the structure in matter provides the source for that information. **Entropy and information are linked**: a very ordered material arrangement (like a crystal or a written text) corresponds to low entropy and high information content relative to a random baseline. This link reminds us that **information is not an ethereal abstraction but something physically embodied**. The "It from Bit" idea captures this arrow well: the bits (information) we observe come from interactions with physical its (things). However, information at this stage (M→I) can be considered raw data—it may exist as records or signals that are not yet interpreted or integrated.

2. **Information → Consciousness (I → C):** Not all information influences consciousness; only when information is processed by a suitable system (like a brain or possibly an AI) does it contribute to conscious experience or knowledge. This link thus represents perception, cognition, and the **emergence of subjective awareness from information processing**. Sensory data (visual scenes, sounds, etc.) enter our nervous system and are integrated into the unified experience of consciousness. Cognitive neuroscience tells us that this integration involves **selective attention, memory, and feedback loops in the brain**. A key aspect is **meaning**: information becomes meaningful (as qualia or as understood data) only when interpreted by a conscious agent. In our model, this arrow is where the qualitative aspect of reality enters: the "bit" becomes an "it" again in the mind, as a thought, a perception, a feeling. Integrated Information Theory (IIT) as mentioned posits that when information is structured in a certain complex way (maximally integrated into a whole), that is consciousness itself. Thus, consciousness can be seen as information that is its own observer, in a manner of speaking. The arrow I→C also covers the formation of **knowledge** – when conscious understanding is formed, raw data is converted into organized information (knowledge structures, concepts). In a human context, this is learning or sense-making. In an AI context, this might be an algorithm detecting patterns or making an interpretation (though whether that is "conscious" remains debated). The philosophical crux here is that **mind is not separate from information; mind is information in a certain state or process**. Chalmers and others have proposed that consciousness might be an intrinsic aspect of information under certain conditions ("panprotopsychism"), aligning with this integrated view. In the circular ontology, we consider consciousness a fundamental domain, but it is deeply intertwined with information.

3. **Consciousness → History (C → H):** Conscious entities act, communicate, and thereby create history. This link represents **agency, creativity, and memory in action over time**. Individual decisions aggregate into social movements; ideas conceived in minds lead to inventions, artworks, institutions—all the stuff of history. When we speak of "history" here, we mean not just a chronicle of events but the structured development of human (or potentially other intelligent beings') presence and impact in the world. From the building of cities to the writing of constitutions, conscious intent and awareness have material consequences that unfold historically. Additionally, consciousness produces **cultural information** that persists through time: languages, books, digital media. This becomes part of the historical record. Even the act of recording history is consciousness feeding into history; historians (with conscious bias or perspective) shape the narrative of what happened for future consciousnesses to absorb. Another aspect of C→H is **cumulative knowledge**: science and technology, products of conscious inquiry, massively change the trajectory of history (consider how understanding germ theory changed medical history, or how computing changed virtually all aspects of modern life). This is consciousness using information to willfully reconfigure later information and material circumstances, which is historical development. We can also include the impact of collective consciousness (e.g., public opinion swings, ideological changes) on historical events like revolutions or reforms. In short, without conscious actors, history (in the human sense) would not exist; there would only be natural events. Consciousness injects purpose, interpretation, and

continuity into events, turning them into a meaningful historical process. This arrow thus infuses **teleology** or directionality into the world – our goals and values shape what happens next. It is where ideas and ideals (from arrow I→C) become real in time.

4. **History → Matter (H → M):** This completes the cycle, showing how historical developments feedback into the material conditions of the world. Across Earth's history, once humans (or any intelligent agents) entered the scene, they began to alter geology, biology, and climate – in other words, **history leaves physical traces**. The Anthropocene, a proposed geological epoch defined by human influence, exemplifies this: human history (industrialization, population growth, agriculture) has transformed the carbon composition of the atmosphere, changed the distribution of species (mass extinctions, domestication), and even altered the planet's surface (cities, deforestation, land reclamation). These changes are literally inscribed in matter: in ice core records, sediment layers, biodiversity levels, etc. But even on smaller scales, every tool made, every structure built is an instance of historical acts reordering matter. A smartphone is a piece of highly organized matter that would not exist without a history of technological development. Moreover, the stock of human artifacts – buildings, machines, waste – constitutes a new layer of matter cycling (sometimes called the technosphere). History also affects matter through warfare (which can scar landscapes), through intentional environmental management or mismanagement, and potentially, in the future, through space exploration (history expanding matter's distribution by sending probes and vessels beyond Earth).

There is also a more subtle aspect: **history affects what matter means and does**. For example, uranium in the ground was just a mineral; after historical developments in physics and engineering, that uranium became fuel for nuclear reactors or bombs – a transformation of its role triggered by historical knowledge. The elements and materials of Earth were reinterpreted and repurposed by historical progress (silicon became the backbone of computing hardware, fossil hydrocarbons became both energy sources and climate-changing agents, etc.). Thus, the arrow H→M includes **the reinterpretation and reconfiguration of the material substrate thanks to historical accumulation of knowledge and capability**. History influences which **forms matter takes** (we have synthesized new chemical compounds, created materials not found in nature like plastics or transuranic elements). One might even say history "writes information into matter" by structuring it (for instance, the information in a written book is encoded in the arrangement of ink on pages – a deliberate historical act embedding information in physical form).

The loop is now closed: the altered material conditions feed into new information (for instance, climate change driven by human history is now generating new data for us – readings of rising temperatures, etc.), which then will influence how future consciousness responds (we learn of the changes and perhaps alter behavior), affecting subsequent history, and so on. The circular ontology is inherently **dynamic**. It describes a **continuous process** where no part is ever truly static or isolated.

A critical insight from this model is that **no domain in the loop is fundamentarily primary in an absolute sense**. They each can be seen as primary from one perspective: matter is primary in a materialist sense (no minds without matter), consciousness could be considered primary in an idealist or panpsychist sense (the reality of experience is the basis on which we know anything), information could be considered primary in a digital physics sense (the universe as information), and history (or time) could be considered primary in a process philosophy sense (reality is fundamentally processes, not things). The circular ontology says: they are **co-equal and co-defining**. Each domain gains meaning only in relation to the others. **Matter matters because it can carry information; information matters because it can be perceived by consciousness; consciousness matters because it drives history; history matters because it shapes the material world that future beings inhabit.** In a fully closed loop, asking "which

came first?" becomes akin to asking "which side of a circle is the beginning?" The question loses meaning; what matters is the **integrity of the whole cycle**.

That said, the circular ontology does not deny sequences or local causal chains. It acknowledges that in time, matter existed before consciousness in our universe's chronology (for billions of years there was matter but no life, let alone consciousness that we know of). However, once the loop closed (once life and consciousness emerged and began feeding back), the subsequent evolution cannot be understood in a purely linear fashion. It's like a loop that closed relatively late in cosmic history but, after closing, started cycling faster and faster (consider the rapid acceleration of historical change once human culture advanced – a kind of positive feedback). Some cosmologists speculate about life and intelligence eventually influencing astrophysical scales – for instance, Freeman Dyson imagined future life might rearrange stars or harness galaxies. If so, the loop might close at an even grander level, with cosmic history (not just Earth's history) feeding back into cosmic matter (redirecting stars, etc.). Even if this is speculative, it underlines the potential in the model: **once a loop is closed, even if it started at a point in time, it can become a dominant factor in future evolution**.

A useful concept for understanding the loop's dynamics is **autopoiesis** or self-production, which we mentioned regarding cells. The entire Earth system with humanity included might be seen as an autopoietic system: we collectively self-produce our world. The circular ontology is akin to saying Earth (or the universe) is engaged in **self-poiesis (self-making)** at multiple levels – physical, informational, and experiential. This is related to the Gaia hypothesis by James Lovelock and Lynn Margulis, which regards the biosphere as a self-regulating system that maintains Earth's habitability. Our model adds the layers of consciousness and culture to Gaia, conceiving it not only as biological feedback but also including technology and thought.

One might ask, **what stabilizes this loop?** Could it spin out of control or break? Stability might come from a balance of flows: energy from the sun (matter) fuels life's information processing and human activities; that energy ultimately dissipates as heat (entropy increase) to space. As long as there's a gradient (like a sun), the loop can cycle and even grow in complexity (scholar Eric Chaisson notes that free energy rate density has increased in systems over time – stars, then life, then society have higher and higher energy throughput per mass, enabling more complexity). If one part of the loop lags or fails, the others may compensate or also degrade. For instance, if conscious insight (C) fails to keep pace with the effects on matter (M) we're causing (like not realizing quickly enough the damage of climate change), history (H) might take a downturn (collapse of societies), which in turn could sharply alter matter (mass extinction). The loop might "reset" to a simpler state with fewer nodes active (like consciousness diminishes if civilization falls). On the other hand, a well-regulated loop, where feedback is intelligently managed, could be sustainable or even achieve a kind of **homeostasis** (Earth stable with technology and nature in balance) or a **positive synergetic growth** (expansion into space, more consciousness, etc., without self-destruction).

The circular ontology also suggests that **meaning and purpose** can be understood within the loop rather than from outside it. Traditional ontology often looked for an external source of meaning (e.g., a divine creator giving purpose to matter and life). In a circular ontology, purpose can be seen as emerging from the loop itself: consciousness creates purposes that shape history and thereby alter the world in ways that enable new purposes. It's an ongoing self-justification. The "meaning of life" in this view might be to participate in this cycle ever more fully – to increase the understanding (I) and richness of experience (C) and positive legacy (H) and sustainable harmony with the material world (M). The loop doesn't require an external justification; its continuation and flourishing become the implicit goal (an idea that resonates with some process philosophers like Alfred North Whitehead or Pierre Teilhard de Chardin who envisioned evolution as a rising spiral of complexity and awareness, headed toward an "Omega Point" of maximal integration – effectively, the loop realizing itself completely).

In summary, integrating the four domains into one cycle provides a powerful lens for interpreting reality. It captures the **full spectrum**: from quarks and stars (matter) to genes and books (information) to qualia and thoughts (consciousness) to civilizations and innovations (history), and back around to laboratories and engines physically altering quarks and stars. It is both humbling and empowering: humbling because we see that we are part of a larger self-perpetuating system (not the isolated masters of nature); empowering because it highlights the creative role of consciousness and culture in shaping the world, and thus the responsibility we carry.

With the integrated model in hand, the next step is to explore how we can study and validate this ontology. This is the domain of **experimental designs and formal modeling**, which we address in Part VI and Appendix E. We will outline ways to empirically test the relationships proposed (e.g., measuring feedback effects, quantifying integration) and describe formal frameworks (mathematical and statistical) to capture the circular dynamics. Essentially, we will transition from "what is the circular ontology?" to "how do we use or verify the circular ontology in practice?"

Before moving on, it is worth noting that the integrated model we propose is itself a kind of **grand narrative** – a story of the universe that is reflexive. It suggests that perhaps **the universe's "aim" (in a metaphorical sense) is to achieve self-awareness and self-organization through this loop**. It brings to mind again Hegel's notion of Geist reaching self-consciousness through history, or Teilhard's idea of the cosmos evolving toward an Omega Point of supreme consciousness. Whether or not one subscribes to teleology, the circular ontology undeniably frames existence as a participatory project: **we (conscious beings) are co-authors of reality's ongoing story**. With this philosophical understanding, we now consider how to concretely approach such a vast concept with the tools of science.

Part VI: Implications and Experimental Explorations of the Ontological Circle

Having articulated the circular ontology, we turn to its **implications and how one might empirically explore or validate this framework**. This part outlines several domains of inquiry and experimental designs that emerge from the theory, as well as the broader significance of adopting a circular ontological view. We discuss how embracing this model could influence scientific research programs, ethical considerations, and our future trajectory. Additionally, we present concrete examples of experiments or observations that could support or refute aspects of the circular ontology. These range from physical measurements to psychological studies to historical analyses, reflecting the interdisciplinary nature of the concept. (Detailed formal protocols and models are provided in **Appendix E**.)

1. Implications for Scientific and Interdisciplinary Research: The circular ontology urges a break from siloed thinking. If matter, information, consciousness, and history are deeply interwoven, then disciplines that traditionally focus on one of these domains must communicate and collaborate. For example, physics and information theory must dialogue (as they do in quantum information science and studies of Maxwell's demon) to understand matter–information links. Cognitive science, neuroscience, and information theory must collaborate to quantify consciousness (efforts like IIT are a step in this direction, measuring consciousness as integrated information). History, sociology, and environmental science need integration with physical sciences to grasp how historical processes impact the Earth system (e.g., Earth system science now integrates human factors into climate models). In a way, a circular ontology provides a philosophical foundation for **integrative science** or consilience (to borrow E.O. Wilson's term for unity of knowledge). It suggests that research should increasingly focus on **feedback loops**: for instance, **biogeochemistry** studies feedbacks between life (biological information processing) and geology (matter); **neurohistory** or **cliodynamics** attempt to find patterns (information) in historical dynamics

that might reflect collective psychological or economic cycles (consciousness↔history interplay). By adopting a circular perspective, researchers are encouraged to consider how their system of interest is both influencing and being influenced by other systems. This could lead to new predictive models: e.g., coupling climate models with models of technological change and policy response (so you model climate (M), data and understanding (I), political will and perception (C), and resulting policies (H) feeding back to climate outcomes (M)).

2. Ethical and Existential Implications: Recognizing that we are part of a self-referential loop changes how we value actions. If history loops back into matter and thereby into future possibilities, then **our responsibility for future conditions is underscored**. Environmental ethics gain a heightened rationale: harming the environment (matter) will curtail future information, diminish future consciousness (e.g., through loss of biodiversity or quality of life), and limit the richness of history to come. Conversely, actions that enrich knowledge, foster conscious development (education, enlightenment), and preserve/improve material conditions will amplify the loop positively for posterity. In a circular ontology, there is a feedback of moral causation: our choices now shape the playing field (material and informational) for future generations' choices. This viewpoint could encourage a more sustainable and long-term perspective. It resonates with indigenous philosophies that consider the impact of decisions on the "seven generations" ahead—essentially acknowledging the historical feedback on material world for future people.

From an existential point of view, the circular ontology offers a kind of meaning: participation in a cosmic self-realization process. Rather than feeling adrift in a purposeless universe, we can see our creativity, knowledge-seeking, and care as literally the universe improving and understanding itself. For some, this might provide a secular sense of spiritual fulfillment or at least a framework to make sense of humanity's place. If one asks, "What are we to do in this vast cosmos?", the circular ontology's answer is: **continue the loop**—increase the amount of integrated information (knowledge and awareness) and improve the material-historical conditions for that loop to flourish. This has a **teleological flavor** (striving towards more complex, conscious, and self-aware states), albeit without positing a mystical end-goal.

3. Experimental Designs – Testing the Links: To treat the circular ontology scientifically, we should identify testable predictions or correlations for each link in the cycle:

- Testing Matter→Information: This link is well-founded in physics and information theory; one could test the limits of how much information can be extracted from physical systems. For instance, experiments on **Landauer's principle** already quantify the physical cost of erasing information. A deeper test might involve quantum experiments where the act of information gain (measurement) changes the state of matter—like Wheeler's delayed-choice experiment (where whether we observe a photon's path or not retroactively determines if it behaved like a wave or particle). The circular ontology predicts that **information is not a passive reflection but an active component** of reality, so one should see matter behaving differently depending on informational interactions (which quantum mechanics confirms in many ways). We could design a test to quantify how different measurement choices (information extraction) lead to different physical outcomes—these are essentially tests of Wheeler's participatory universe idea.

- Testing Information→Consciousness: How can we verify that integrated information corresponds to consciousness? One line of experiments is in neuroscience: use perturbations and recordings to measure integrated information (phi metric) in different brain states and compare with reports of consciousness. For example, **measure phi for awake vs. anesthetized brains** and see if phi drops significantly when consciousness fades (Tononi and Koch did argue that phi correlates with states of consciousness). Another approach: build artificial networks of varying architectures and see if any objective measure of information integration correlates with behaviors that we associate with

consciousness (like global broadcasting of information, flexible self-modeling, etc.). If the circular ontology is right, simply adding more raw computing power (information processing) may not yield consciousness unless it's organized in a reciprocal, integrated way. This could be tested by comparing, say, feedforward neural networks vs. recurrent neural networks on tasks that might require an "inner model" (recurrent networks have loops and might show more signs of adaptive, context-dependent processing akin to awareness). Additionally, **clinical studies**: use EEG or neuroimaging to examine brain integration in coma patients vs. conscious patients – indeed such studies have found that patients in vegetative states show much lower information integration (measured by stimuli responses) than conscious individuals, even if reflexes might be present. If future research solidifies phi or a similar measure as a consciousness index, it strongly supports the notion that consciousness is about information structure, not about any special substance beyond that.

- Testing Consciousness→History: This is tricky because it's a broad claim, but essentially it's asserting that changes in collective consciousness (ideas, values, knowledge) cause changes in the direction of history. While we cannot run controlled experiments on whole societies easily, we can do historical analyses and **statistical studies**. One could operationalize "collective consciousness" via proxies: e.g., literacy rates, prevalence of scientific rationality (number of scientific publications, etc.), or certain value surveys of populations, and then examine correlations with measures of societal development such as economic growth, conflict, innovation rates. Alternatively, one could look at specific historical case studies where an introduction of new knowledge or ideology clearly pivoted events (for example, how the Enlightenment's spread of certain ideas led to political revolutions). These aren't laboratory experiments, but comparative historical analysis can be rigorous (using methods of **cliometrics** or **cliodynamics**, where mathematical models are applied to history). For instance, Peter Turchin's cliodynamics models treat social unrest cycles with variables including social trust or morale (collective psychological factors) and then test those models on historical data series. If consciousness (or at least human cognitive factors) strongly drive his models, it implies the C→H link is quantifiable. We could also simulate societies in agent-based models where agents have certain levels of knowledge or biases and see how different collective mindsets yield different historical outcomes (war, cooperation, collapse, etc.). The hypothesis would be that **more informed and self-aware societies navigate history differently** (perhaps more successfully avoiding self-destruction, for example). Over long periods, one could test if increasing knowledge (I→C realized) correlates with slower growth in material entropy or more control over the environment (H→M moderated), implying feedback. We might analyze global trends: as scientific knowledge grew (Enlightenment onward), did the trajectory of human population and economy drastically diverge from prior patterns (it did, in the Industrial Revolution)? And now, as awareness of global challenges increases, are there detectable changes in historical trends (like flattening of certain growth curves due to conscious policies)? These are complex to attribute but align with our model's expectations.

- Testing History→Matter: Some aspects of this link are sadly being "tested" unintentionally by humanity – e.g., the extent of climate change and biosphere alteration due to our historical industrial activity. But beyond establishing that indeed human history alters matter (which is empirically undeniable at this point, from CO2 levels to extinction rates), we can look at scale and mechanism. **Earth observation experiments** and models can quantify how much of current matter-energy flows are directed by human (historical) activity versus natural processes. For instance, how does human-driven sediment movement (through agriculture, damming, etc.) compare to natural sediment flow? It turns out humans move enormous amounts of earth, rivaling natural processes – indicating historical forces now shape geology. One can also probe feedback: how do these material changes feed back into socio-historical outcomes? (e.g., climate

change leading to societal stress – a H→M→I→C→H loop). To test directly, consider interventions: if we deliberately alter some material condition, can we measure a clear historical response? One benign example: releasing open data on environmental conditions (an information action but tied to material measurement) led to global climate accords (historical event), which if upheld will change physical emissions. While multi-step, it demonstrates that making matter's state known (I) changes consciousness (C) changes history (H) in service of adjusting matter (M). A controlled experiment might be on a smaller scale: e.g., a community experiment where improving environmental conditions (like re-greening a neighborhood) is tested for its effects on community behavior and resilience (history at small scale). Some urban studies effectively do this – see whether adding green space reduces crime or improves social cohesion. If so, that's H→M (lack of green, a result of historical neglect or policy) affecting C (well-being, which affects social outcomes in H). We can invert that: to test H→M directly, one could measure an environment before and after a known historical event such as a policy change that protects a habitat and see if the habitat recovers. While straightforward, it's still verifying that human decisions tangibly change physical states (which of course they do).

4. Toward a Predictive Science of the Loop: Ultimately, if the circular ontology is valid, we should be able to build an integrated **model-of-everything** (in a limited sense) that includes at least coarse representations of each domain and their feedback. For example, a model might include equations for population (matter organized into living beings), technology level (information available), worldview or education level (average consciousness capability or values), and environmental state (matter condition). Then include interactions: technology and worldview affect environment (through resource use or protection), environment and technology affect population (through carrying capacity), etc., closing the loop by having population and worldview feed back to technology development (more people and freer thinking fosters innovation), and so on. Running such a model on a computer – effectively simulating an Earth with various initial conditions – could yield scenarios of the future. This is similar to integrated assessment models used in climate projections (which couple economic models to climate models). A circular ontology approach would try to incorporate perhaps a metric for collective "wisdom" or awareness that can vary, to see how outcomes differ. If high awareness societies manage a stable loop (sustainability) whereas low awareness ones crash (environmental collapse or conflict), that would illustrate in silico the importance of the consciousness factor (C).

Another predictive angle is to see if certain **scale-invariant patterns** appear due to the loop. Many complex systems show power-law distributions or cycles. We can examine if historical time series (like innovation rates, population, energy use) show signs of feedback-induced acceleration or stabilization. E.g., does knowledge accumulation accelerate exponentially or level off? There's evidence of exponential growth in number of publications, Moore's law in computing, etc. If those eventually slow (some say Moore's law will) maybe consciousness collectively redirects to new paradigms – a kind of phase change in the loop. Prediction might then focus on identifying such phase transitions (like the Industrial Revolution was one, the Information Age another; maybe a Sustainability Revolution could be next if the loop compels it to avoid breakdown).

5. Practical Experiments in Psychology and Society: On a smaller scale, one can design direct experiments with human participants to probe mini loops:

- Metaphor's effect on perception: Since Part II stressed metaphor-data-form loops, we can test how providing different metaphors alters individuals' interpretation of data. For example, in a psychology experiment, give two groups the same crime statistics (data about crime rates) but frame them with different metaphors (one group reads that "crime is a beast ravaging the city," another reads "crime is a virus infecting the city"). Studies have shown that such framing affects what solutions people propose (the beast metaphor group tends to support enforcement, the

virus group favors social reform, by analogy). This directly demonstrates a loop: the metaphor (conscious framing) affects interpretation (information meaning) which affects presumably future actions (history/policy preferences).

- Collective problem solving: Create a closed loop in a lab microcosm. For instance, an experimental game where participants collectively manage a resource (fish in a pond simulation). They have a resource (matter analog), they get data on its status (information), they discuss strategy (consciousness, deliberation), and their extraction decisions create an outcome over repeated rounds (history). By varying parameters (like giving them better data vs. poor data, or encouraging more reflection vs. forcing quick decisions), one can see how those factors affect outcomes. A hypothesis: groups with better shared information and more reflection (higher I and C in the loop) manage the resource more sustainably (better H→M outcome). This would support the beneficial synergy in the loop.

- Neurofeedback and self-reference: An individual experiment: use **real-time fMRI neurofeedback** to let a person see their own brain activity (information about their matter state) and try to control it with their mind (conscious effort). Success in such experiments (people can learn to reduce their pain perception by seeing and adjusting their brain activity in pain centers, for example) is a direct illustration of mind influencing matter (C→M via biofeedback) using information as intermediary. It shows a conscious loop within one person: see brain state (I), willfully alter thought (C) which changes brain (M), which is then seen again. This is a microcosm of our whole ontology in one skull. It's experimentally measurable (compare brain and subjective reports with vs without feedback training). Effective neurofeedback confirms that consciousness can intentionally modulate physical states when provided the right information mirror.

6. Formal Analysis and Statistical Protocols: To confirm any of this rigorously, we need proper statistics. Appendix E outlines how one might use **ANOVA (analysis of variance)** or regression to assess, for instance, how much variance in a historical variable (like environmental quality index) is explained by a consciousness-related variable (like education level) vs. purely material ones (like GDP). A statistically significant contribution of consciousness proxies would validate that link quantitatively. Likewise, one can do **time-series analysis**: cross-correlation functions between, say, spikes in information production (maybe patents filed) and subsequent changes in material measures (energy efficiency improvements). If patents lead efficiency gains with some lag, it suggests I→M effect through C and H intermediate steps. In experiments, simple **t-tests** can check differences between conditions (like metaphor framing experiment: a t-test on whether the mean policy preference differs significantly between metaphor conditions). For complex simulations, one might use **Monte Carlo methods** to see distribution of outcomes and check robustness.

The challenge is that many of these processes are noisy and multi-factorial. Therefore, **protocols to isolate loops** are important. For example, in the resource management game, to isolate the effect of consciousness quality, one could keep resource dynamics constant and just alter whether players can communicate or not. Communication allows shared intentionality (a higher-order consciousness phenomenon). If groups who communicate achieve better outcomes, it quantifies the role of conscious coordination in history-matter management. One could then statistically analyze results with and without communication (an independent variable) against resource remaining after the game (dependent variable). A clear difference with $p < 0.05$ significance would support our theory.

In summary, while the circular ontology is broad, it does not reside only in abstract philosophy; it **yields hypotheses** that various branches of science can test. By validating each link and the feedback structure, evidence for the overall model accumulates. Conversely, if any link were conclusively falsified (imagine if, per impossibile, we found conscious states do not actually depend on information structure but on

something else, or that human knowledge has zero impact on material outcomes, etc.), then the ontology would need revision.

So far, empirical knowledge favors the idea that indeed: - Physical states underlie information and respond to measurement (quantum mechanics, thermodynamics). - Consciousness correlates with integrated information in the brain. - Human conscious activity steers historical events and the physical state of our planet (ample evidence). The task is to move from correlation to precise understanding of causation and dynamics, which the experiments and models above aim to do.

7. Future Vision – Steering the Circle: If we accept the circular ontology, an ultimate implication is that we could intentionally steer the loop. That is, with enough understanding, humanity could guide the development of the loop towards desired outcomes (perhaps this is an extension of the Enlightenment project of rational self-determination, but on a planetary scale). For instance, recognizing feedback delays (like CO2's effect on climate) means consciousness (us) can plan far ahead historically to mitigate them (we need to act now for decades later benefit). Recognizing our biases (information processing limits) means we design decision-making processes to compensate (like creating institutions that force long-term thinking, or using AI to help process massive data for decisions). Essentially, we could become **active moderators of our ontological loop**, improving its stability and output (where output might be collective well-being, knowledge, and harmony with environment).

One futuristic extension: **AI and the loop**. If we create AI that attains some level of consciousness or at least advanced information processing ability, the loop gains a new element. AI could accelerate information analysis (I), possibly develop a form of machine consciousness (C), influence society (H), and manipulate matter (robots, nanotech) (M). This could tighten the loop's cycle (things change faster) and maybe even risk spinning out (if not managed, e.g., hypothetical AI causing uncontrolled changes). Experimentation in AI governance and human-AI collaboration thus also becomes an important frontier to ensure the loop remains beneficial and not destructive. The circular ontology provides a framework to think about AI as not just a tool but a participating agent in the ontology potentially.

Finally, **Appendix E** will lay out the formal side: modeling these ideas with equations, diagrams, and specific protocols. That section will present mathematical notation for category theory mapping of the loop, derive simple entropy flow equations, and outline step-by-step statistical testing methods. Those formalizations aim to ground the somewhat abstract discussion here into concrete, repeatable science.

In conclusion of Part VI, the circular ontology guides us to look at the world as a unified, self-updating system. It compels us to adopt an ethical stance of caretaking that system (since we are the system caring for itself) and a scientific stance of humility (no isolated silo can capture truth) combined with ambition (maybe we can understand the whole loop by connecting our knowledge). The experiments and designs proposed are early attempts; as our understanding grows, we may develop more sophisticated ways to probe the "connective tissue" between matter, information, mind, and history. In doing so, we actively participate in the very ontology we study—the ultimate reflexive act of a self-aware universe.

Now, with all parts of the narrative completed—from prologue through detailed exposition and analysis—we step back into a broader, more contemplative space. The **Epilogue** will reflect on what we have learned and what it means, in a voice that blends the scientific with the poetic, consistent with the tone of a journey's end that is also a beginning (for in a circle, every end loops to a new start).

Epilogue

We circle back to the beginning. Standing beneath a night sky glittering with stars, we cannot help but wonder: are we, the curious observers, anything more than transient specks in a vast material cosmos? According to the ontology we have traced, we are more—**we are the cosmos looping back on itself, matter come alive to witness its own majesty**. The atoms in our bodies were forged in stars; those atoms now form neurons that carry thoughts about stars. The narrative of matter, information, consciousness, and history is not four separate stories but one grand, recursive tale. It is a tale with no final chapter, only continual revision, as the author and the protagonist are ultimately the same: **the universe itself**.

There is a profound poetic symmetry in this realization. The **metaphor of the Ouroboros**, introduced in our prologue, resonates even more deeply now [1]. The universe is an Ouroboros that has, over eons, learned to hold up a mirror to itself. In that mirror, it sees **beauty and terror, order and chaos, creation and destruction**—all the dramas of history and all the laws of physics entwined. Through us, the cosmos has eyes and ears; through our science, it has understanding; through our art, it feels aesthetic self-appreciation; through our struggles and ideals, it seeks moral direction. **We are not external observers dropped into the world; we are participants in its circular unfolding**, threads in the tapestry and also the weavers.

As we contemplate this circular ontology, a subtle shift in perspective occurs. Traditional worldviews often asked, “What is the foundation of everything? Is it matter? Mind? God? Equations?” The circular ontology suggests a different question: “How do the fundamental aspects of reality continuously create each other?” This invites a stance of **reverence for relationships** rather than for isolated things. The sacred, if one may use the term, lies in the **connections**: the spark when insight (consciousness) illuminates fact (information), the bond when shared knowledge unites a community to change their world, the delicate feedbacks that keep an ecosystem (matter and life) in balance through time (history). In a sense, meaning emerges **in-between**—in the arrows of our cycle, not just the nodes. This intertwining gives rise to a kind of cosmic empathy: to care for the environment is to care for the cradle of mind; to foster human education and wisdom is to enrich the very universe’s self-awareness; to preserve history and heritage is to maintain the memory of the world.

We might imagine, in a flights of fancy yet grounded in our framework, that if the universe had a voice, it would speak through our poets and philosophers, expressing awe at itself. When Whitman wrote, “I contain multitudes,” was that not the voice of star-stuff marveling at the multitudes it has become? When a historian chronicles the rise and fall of civilizations, is that not the universe reflecting on its own narrative arc? And when a child learns something new—eyes widening with wonder—that is the universe experiencing the joy of discovery yet again, like the first light that broke over creation.

This view also casts responsibility in a new light. If reality is a circular interplay, **every action reverberates through the whole**. A careless act that damages the earth isn’t just an isolated event; it is the universe undermining part of itself. Conversely, every act of kindness, every inquiry for truth, every creative endeavor is the universe enriching its collective being. In this grand recursion, our individual lives are small loops within larger loops, but significance is not lost in smallness. On the contrary, significance is amplified by connection. We find purpose in being **effective links** in the chain: conduits that take what came before (genetic, cultural, intellectual inheritance) and transform it—maybe just a little—before passing it on. This process is history, and we are its agents.

There is a moving harmony in knowing that **the data we collect, the stories we write, the equations we solve, and the dreams we dream all become part of the fabric of the world**. One day, long after we’re

gone, there may be other conscious forms—perhaps evolved from us, perhaps artificial, perhaps alien—who will look back on our era's records. We will be a chapter in the universe's autobiography. Knowing this, how should we write that chapter now? With insight and compassion, hopefully, weaving lessons that will enlighten those future minds. The circular ontology instills a sense of continuity: we are not isolated in time any more than in space. We stand upon countless feedback loops of the past (the successes and failures of our ancestors live in our institutions and sciences), and we are building loops that will support future beings.

As T. S. Eliot observed, the end of all our exploring is to arrive where we started and know the place for the first time. Here at the end of our exploration in this paper, we return to that simple awe of existing in a universe that can ask questions. The place we started was perhaps a confusion—"How do matter, information, mind, and history relate?"—and the place we return to is clarity: **they relate like the seasons in a year, each giving rise to the next**. We indeed know this place anew: the solid earth beneath our feet (matter) is not inert background but an actor in the story; the information swirling around us (in books, screens, conversations) is the delicate thread connecting mind to world; our consciousness, pondering these words, is the universe rendering itself sensible, one thought at a time; and history is the grand mosaic of all such moments, a mosaic still in the making.

In closing, a final image: imagine the universe as a great circle whose circumference is everywhere and center is nowhere (to adapt Pascal's description of nature or God). On that circumference are inscribed all the equations of physics, all the words of literature, all the notes of songs, all the faces of creatures, all the stars and galaxies—an endless tapestry of matter, information, consciousness, and history. The circle turns, and with each turn, new patterns emerge from old ones. Yet, fundamentally, it is one majestic Whole. Our task and our privilege as thinking beings is to **help the circle know itself**, to trace out the connections, and perhaps, gently, to guide its turning toward truth and beauty.

The ontology we have proposed is circular, but it is not a closed loop of fate; it is an **open circle**, welcoming new entries, new voices, new understandings. It teaches us that **the end is in the beginning** and **the observer is in the observed**. And so the story continues. We end this academic journey here, but the real journey—the cosmic round of matter, information, consciousness, and history—goes on, inviting us to participate knowingly. As we step back into the flow of life from the standpoint of this knowledge, we carry with us a unifying vision: **we are all aspects of one unfolding reality, turning together like a great wheel, learning to see ourselves in each turn**. The circle of being is complete, yet ever new—an eternal Ouroboros that forever creates and discovers itself.

Appendix E: Formal Models and Experimental Frameworks

E.1 Category-Theoretic Formalization of the Ontological Loop:

To formalize the circular ontology, we introduce a category-theoretic representation. Let us define a category $\mathbf{Ont}$ (for "ontology") which encapsulates the transformations between matter, information, consciousness, and history. The objects in $\mathbf{Ont}$ can be taken as state-spaces or configurations of each domain, and the morphisms as processes that convert one type of state to another. For simplicity, denote: - **M** as the object representing the state of **matter** (physical configuration of the world). - **I** as the object for **information** states (data, knowledge representations). - **C** for **consciousness** states (mental configurations, perhaps characterized by cognitive or neural states). - **H** for **history** states (the socio-environmental configuration at a given time).

We then postulate the existence of morphisms corresponding to each directed link in our loop: - **f:** M → I, a morphism that maps a physical state to informational state. (For example, a measurement process or data encoding: given a state of matter, f produces a description or data record of it.) - **g:** I → C, mapping information to a conscious state. (For instance, perception or learning: given data, g yields a state of understanding or awareness in a mind.) - **h:** C → H, mapping a conscious state to a historical state. (An action or communication: a decision by conscious agents leads to a change in the world's state, e.g., a societal action or creative output.) - **j:** H → M, mapping a historical state to a material state. (The accumulation of effects over time: given a state of the world shaped by human activity, j yields the new physical configuration. Essentially, H → M is a "forgetful" projection of the historical state to underlying matter, or the natural evolution of the environment under historical influences.)

These morphisms compose in sequence: **j ∘ h ∘ g ∘ f: M → M** is an endomorphism on object M. This endomorphism represents one full cycle of the ontology. If we imagine "stepping forward" through one cycle (say, a unit of time or a full round of interaction), **Φ = j ∘ h ∘ g ∘ f** is the transformation that matter undergoes after the loop.

One can study fixed points of this composite Φ. A **fixed point** in this context would be a state M such that Φ(M) = M, meaning a material configuration that, after going through one loop of generating information, feeding consciousness, producing history, and altering matter, returns to the same material configuration. Trivially, a static unchanging universe (no differences at any step) is a fixed point, but we are more interested in non-trivial fixed points or attractors which correspond to steady states* of the loop (for example, a sustainable society in equilibrium with its environment might correspond to an attractor in this dynamic where material conditions oscillate within bounds, information and consciousness flourish and reinforce each other, etc.).

Category theory also offers the concept of **functors** to formalize analogies or metaphors as discussed in Part II. For example, consider a category **Domain** for a source domain of metaphor and **Range** for a target domain. A metaphor can be modeled as a functor **F: Domain → Range** that maps objects and morphisms in the source to objects and morphisms in the target, preserving structural relations. In the context of our ontology loop, the formation of scientific theories can be seen as a functor from the category of **natural phenomena** (with objects as physical processes, morphisms as causal relations) to the category of **models** (objects as theoretical constructs, morphisms as mathematical or logical implication). This functorial perspective ensures that the **structure** (form) is preserved between reality and theory via the metaphorical mapping, making it clear why good metaphors (or models) yield predictive power – they preserve relationships. Errors in metaphor can be seen as functor mappings that are not structure-preserving (hence leading to incorrect inferences).

Within **Ont**, one might also define a **monoidal structure** to represent the simultaneous combination of subsystems. For instance, if we consider two independent loops (say two separate societies or two minds), the monoidal product ⊗ could combine their states. A scenario of interaction (like cultural exchange) then might be represented by **monoidal functors** mapping the monoidal product of two ontology categories to a single unified ontology category (two loops intertwining). These higher-order category constructions can get complex, but they hint at how to scale the model from one closed loop to networks of interlocking loops (e.g., the global network of human societies).

E.2 Entropy and Information Flow Models:

We introduce quantitative measures to represent the flow of entropy (disorder) and information (order) through the loop. Let: - $S_M(t)$ = entropy associated with the material state at time t (in a thermodynamic sense, e.g., entropy of Earth's environment or another closed system of interest). - $S_I(t)$ = information

entropy (uncertainty) at time t in the domain of knowledge/data. - $S_C(t)$ = an entropy-like measure for consciousness at time t. This could represent uncertainty in conscious state or inefficiency in information integration. (One possible proxy is the entropy of neural firing patterns or the diversity of brain states – though a high entropy brain state might correlate with either rich consciousness or disorganized thought depending on context. For a simple model, one might treat S_C as maximum when consciousness is completely disintegrated (like unconscious or random firing) and lower when consciousness is highly integrated and ordered.) - $S_H(t)$ = entropy in the historical/social domain at time t. This could be proxied by measures of disorder in society or environment – for example, sociopolitical entropy (how unpredictable or unstable social states are) or ecological entropy (biodiversity loss, etc.).

One idealized model assumption: the total entropy of the combined system may increase in accordance with the Second Law of Thermodynamics. However, subsystems can trade entropy. For instance, a decrease in informational entropy (learning something, thus reducing uncertainty) must be paid for by an increase in entropy elsewhere (heat dissipation in computers or brains). We can express this with a balance equation:

$$\Delta S_M + \Delta S_I + \Delta S_C + \Delta S_H \geq 0,$$

over a complete cycle (where Δ denotes change over that cycle). This inequality reflects that any local entropy reduction (making things more ordered in one domain) must be offset by entropy exported to another domain or to the wider environment.

Consider each link: - **M → I:** When matter yields information, there is often a **decrease in uncertainty** about the material system (we gain knowledge). For example, measuring a physical quantity precisely reduces our uncertainty (information entropy) about that quantity to nearly zero. According to Landauer's principle, the act of obtaining and recording that information will generate at least $k_B T \ln 2$ of thermodynamic entropy for each bit of information erased or used. If we denote ΔS_I (negative because uncertainty fell) and ΔS_M_env (entropy dumped into some environment like a heat bath), we could write:

$$-\Delta S_I = \Delta S_{M,\text{env}}.$$

This is a rough equality if done optimally (erasure at Landauer limit), or inequality (≥) if less efficient. Essentially, one might treat measurement as transferring entropy from the information sector to the material sector (the measuring apparatus and its environment). In modeling, we could set a parameter for measurement efficiency η such that

$$\Delta S_M = \frac{1}{\eta}(-\Delta S_I),$$

with η ≤ 1. Efficient information extraction (close to reversible computation) means η is close to 1 (minimal entropy generated per bit).

- **I → C:** As information becomes conscious understanding, one could consider that the brain (or mind) assimilates data, thereby reducing entropy in the information domain (the data is no longer random bits; it's arranged into meaningful knowledge in the mind's model). Within the brain, however, this may correspond to **negative entropy** being imported (the brain's synapses might get more ordered by learning). The brain certainly expends energy (increasing entropy via metabolism) to do this ordering. Let's denote ΔS_C (which might decrease if the conscious state becomes more organized with new knowledge) and ΔS_M_brain (entropy produced by the brain's energy use). A simplified relation:

$$-\Delta S_I = \Delta S_{M,\text{brain}} + (-\Delta S_C).$$

If consciousness becomes more ordered (ΔS_C negative), the brain must have produced at least that much entropy plus what's needed for the computing overhead. In a steady baseline conscious state, one might treat S_C as roughly constant and instead focus on the trade between S_I and S_M_brain. The second law demands the brain's entropy output ≥ the drop in information entropy of the learned material:

$$\Delta S_{M,\text{brain}} \geq -\Delta S_I.$$

- **C → H:** When conscious decisions affect history, this is hard to quantify in entropy directly. One approach: consider societal entropy S_H measuring disorder (like conflict, randomness of events). A conscious effort like implementing policy, planning, tends to impose order on societal dynamics (ideally reducing randomness, e.g., enforcing rule of law reduces unpredictability in daily life, which is a form of entropy reduction in social systems). However, implementing order requires work—convincing people, building institutions—analogous to a Maxwell's demon scenario in social context. The "entropy" cost might be burnout or complexity costs, and it could show up as entropy exported to environment (e.g., resource consumption to maintain order, which increases environmental entropy, S_M). We might write a qualitative exchange: conscious direction lowers social entropy but raises physical entropy (through energy use). For example:

$$-\Delta S_H = \Delta S'_{M,\text{env}} + \Delta S_{C,\text{fatigue}},$$

where S_{C,\text{fatigue}} is like an entropy or uncertainty increase in the minds (as complexity taxes cognition). This is speculative, but we can see that high organization societies often come at high energy cost (low entropy in human structures, high entropy waste heat to environment).

- **H → M:** History altering matter clearly increases entropy in many cases: burning fossil fuels, mining ores and dispersing them, deforestation—these tend to increase environmental entropy (more greenhouse gases = more entropy in atmosphere, more mixing of materials, loss of structured ecosystems). There are counter-examples: deliberate efforts at conservation or cleaning up pollution locally reduce entropy (at the expense of energy). So we can think of H as an agent that can either raise or lower S_M depending on choices, but overall on Earth so far, ΔS_M due to human history has been a large positive (we have increased entropy globally). The Earth is not a closed system though; we dump entropy to space via infrared radiation (heat). A future steady-state scenario might try to keep S_M from increasing too much in undesirable forms (pollution, disorder) by converting as much waste as possible to radiation entropy leaving Earth (basically using energy to maintain order—again pushing disorder outward).

In building a **system of equations**, one might combine these: For instance, across a small time interval dt:

$$\frac{dS_M}{dt} = f_1(I, C, H) + \Phi_{\text{out}},$$

$$\frac{dS_I}{dt} = f_2(M, C)$$

(likely negative when good measurements are happening and positive when data is lost or noise accumulates),

$$\frac{dS_C}{dt} = f_3(I, H)$$

(e.g., consciousness entropy might drop when new info is structured but increase under stress or overload),

$$\frac{dS_H}{dt} = f_4(C) + f_5(M)$$

(societal entropy could be driven down by conscious management or up by material shocks like disasters).

We'd include dissipation terms Φ_{out} for entropy flowing out to environment (space). Ultimately, the only way Earth avoids saturating with entropy is radiating it away, so any local entropy reduction must go into Φ_{out}.

A concrete sub-model: **Growth and Knowledge Feedback.** Suppose we model global entropy roughly as proportional to waste heat generation (energy consumption) and knowledge as negative entropy in information structures. A simple equation pair:

$$\frac{dK}{dt} = aK \ln\left(\frac{1}{S_M/S_{M0}}\right),$$

$$\frac{dS_M}{dt} = b\frac{dK}{dt} + cS_M,$$

where K is knowledge (inverse of S_I in effect), S_M is environmental entropy or resource depletion measure. The term $aK\ln(1/(S_M/S_{M0}))$ is inspired by notions that knowledge grows faster when there's more to learn from environment or more challenge (if environment entropy S_M increases, perhaps that spurs knowledge growth to combat it, up to a limit). b translates knowledge gains into entropy reduction (perhaps each unit of new knowledge helps mitigate some entropy by efficiency), while cS_M is natural entropy increase (c > 0, like business-as-usual degradation). This is speculative but could yield a differential equation system showing possibly a stable fixed point (knowledge high enough to stabilize S_M) or runaway (if c term dominates, S_M grows too high, reduces knowledge growth capacity if environment gets too chaotic, etc.). One could analyze stability by linearizing around equilibrium.

E.3 Statistical Analysis Protocols:

To test and estimate parameters in such models, we propose the following statistical protocols:

- **Data Collection:** Gather time-series or panel data for proxies of M, I, C, H. For example, on a global scale: M proxy = atmospheric entropy (function of temperature distribution) or simply CO2 concentration; I proxy = global data storage or literacy rates or number of researchers; C proxy = something like average educational attainment or prevalence of democratic/free institutions (as a rough measure of conscious societal deliberation) or even global IQ or health indices; H proxy = some metric of world order such as conflict frequency (high conflict = high entropy) or economic inequality (could interpret high inequality as high "structural entropy" or vice versa depending on perspective). These proxies are debatable, but one must choose operational measures.

- **Correlation and Granger Causality:** Compute correlation matrices and perform Granger causality tests to see if changes in one variable statistically precede changes in another. For instance, does an increase in knowledge (I proxy) Granger-cause a decrease in pollution (M proxy) after some lag? Does a change in consciousness proxy (e.g., more democratic governance) Granger-cause improvements in H (less conflict) or M (more environmental protection)? Granger

causality is assessed by regression: $X_t = \alpha X_{t-1} + \beta Y_{t-1} + \dots$. If including past Y significantly improves prediction of X ($p < 0.05$ for β), then Y Granger-causes X.

- **Structural Equation Modeling (SEM):** Construct an SEM with latent variables for the four domains (since our proxies are imperfect) and directed edges corresponding to the hypothesized causal links: M → I, I → C, C → H, H → M. Fit this model to data and see if the path coefficients are significant and of expected sign. SEM will also give overall fit indices (like RMSEA, CFI) to see if the circular model is plausible. One might include a cyclic structure which is a bit tricky as SEM is usually acyclic; could treat it in two-stage (time-lagged SEM, like cross-lag panel analysis).

- **Intervention Analysis:** Identify historical events that serve as quasi-experiments for one link. For instance, the introduction of the internet (~1990s) drastically increased information availability (I jump) globally; did global consciousness measures (like awareness of global issues, measured via surveys or international cooperation frequency) improve subsequently compared to prior trend? One can use **Interrupted Time Series Analysis**: fit a time series model to pre-intervention data, project forward, and compare actual post-intervention to projected to detect significant level or slope changes. E.g., look at CO2 emissions trajectory before and after major environmental accords (which represent conscious historical decisions). If slope of emissions slowed after accords more than expected by chance, that supports C→M efficacy.

- **Laboratory Experiments and ANOVA:** At micro scale, as described earlier, we can run controlled experiments (e.g., group resource management game with and without communication) and use ANOVA to see if the mean outcome differs by condition. For example, two-factor ANOVA could assess influence of an "information transparency" factor (full info about resource vs. partial info) and a "conscious deliberation" factor (allowed to communicate vs. not). Dependent variable: resource remaining after game (higher = better sustainable outcome). We expect main effects: transparency (I clarity) yields more resource remaining, communication (C collaboration) yields more remaining, and possibly an interaction (together they yield more than sum of parts because of synergy).

- **Regression Models:** Fit multi-variable regressions to quantify relationships. For example,

$$\Delta \text{Environment}_{t \to t+1} = \beta_0 + \beta_1 \text{Research/GDP}_t + \beta_2 \text{Education Level}_t + \beta_3 \text{Policy Index}_t + \epsilon,$$

  where environment change is e.g. change in emissions or pollution, research/GDP is information/knowledge investment, education is consciousness proxy, policy index is historical conscious action. We check significance of β's. A positive β1 (more R&D correlates with improvement in environment) implies I→M benefit. A positive β2 implies C→M benefit (educated populace tends to improve environment). β3 shows direct H (policies) effect. These analyses can be done across countries (panel data) or across time.

We may also incorporate **lag terms** if effects take time:

$$\text{Env}_{t+1} = \alpha \text{Env}_t + \beta \text{Knowledge}_t + \gamma \text{Consciousness}_t + \dots$$

and perform regression or even machine learning time-series forecasting to see feature importance.

- **Significance and Uncertainty:** Use appropriate significance tests (t-tests for coefficients, F-tests for model, etc.). Also, because of possible autocorrelation in time series, use Newey-West adjusted standard errors or difference stationary forms to ensure valid inference. In ANOVA, ensure assumptions (normality, equal variance) or use non-parametric tests if needed.

- **Bayesian Approaches:** One can also deploy Bayesian networks or dynamic Bayesian models encoding the loop structure and update beliefs given data. This is useful when data is noisy and incomplete. The output would be posterior distributions for influence strengths (like probability that consciousness influence on history is above some threshold). Bayesian model comparison could check if a model with the loop fits better than alternative models (like a purely linear no-feedback model).

E.4 Example Calculation:

As an illustrative calculation, consider the resource management game experiment: - We have 4 groups of participants: 1) Control: no communication, low information (they get only minimal feedback about resource levels). 2) Comm-only: communication allowed, but still low info (they can strategize but don't have good data). 3) Info-only: high information (real-time precise data about resource) but no communication (each decides individually). 4) Full: high information + communication. We run 10 independent games for each condition and measure % resource remaining after a fixed number of rounds.

Suppose results (mean % remaining ± SD): 1) Control: 30% ± 10 2) Comm-only: 45% ± 15 3) Info-only: 50% ± 12 4) Full: 70% ± 10

ANOVA on these four means would likely show a significant effect ($p < 0.01$). Post-hoc comparisons might find Full > others significantly, Info-only > Control, Comm-only > Control, and maybe Full > Info or Comm individually. We could model this outcome with a two-way ANOVA (2x2 factors): - Info factor: low vs high - Comm factor: no vs yes The cell means approximated from above: Low+No (Control) = 30, Low+Yes (Comm-only) = 45, High+No (Info-only) = 50, High+Yes (Full) = 70. Main effect of Info: (50+70)/2 – (30+45)/2 = (60 - 37.5) = +22.5 percentage points (info improves sustainability on average). Main effect of Comm: (45+70)/2 – (30+50)/2 = (57.5 - 40) = +17.5 points (communication improves outcomes). Interaction effect: Full - Comm-only - Info-only + Control = 70 - 45 - 50 + 30 = +5. So slight positive interaction (the combination yields about 5 points more than the sum of individual improvements—synergy). F-tests would check if these effects are statistically significant relative to variation. Given differences of ~20 points, likely yes (with 10 trials each, one could estimate F ~ effect^2/(variance/10); rough numbers might yield F ~ (20^2)/((12^2)/10) ~ 400/(14.4) ~ 27.7, highly significant).

This supports hypotheses: - Info (I) helps (I→C or I→H link effectiveness). - Comm (C collective) helps (C→H link). - Both together help most (confirming loop synergy: I and C reinforce each other to produce best historical outcome for resource).

Such controlled experiments lend micro-level evidence for the benefits of information and conscious coordination in managing material resources—a microcosm validating the loop's positive feedback potential.

E.5 Toward a Unified Bibliography and Footnote System (Chicago Style):

Finally, all references cited throughout the paper are collected below in Chicago style. In the main text, we have used an author-date citation format (with occasional direct online citation markers【】 to comply with source attribution in this medium). In a formal publication or print, those would be replaced with either parenthetical citations or footnotes. The bibliography provides full source information, allowing the interested reader to trace the intellectual and empirical foundation of this work.

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1 Hofstadter’s “Strange Loop” of Consciousness: Note on the Self as a Feedback System | by Adnan Masood, PhD. | Aug, 2025 | Medium
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